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Simulation of very high snow loads on solar thermal collectors

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Abstract

A new test device for the simulation and testing of very high mechanical loads on sloped roofs for a realistic rating of the snow load resistance of solar thermal collector systems was developed. Several sensors and cameras visualize the occurrence of snow load-induced damages during the test to identify structural weak points of a collector and its mounting system. In collaboration with the Swiss building insurances, a test and certification procedure was established aiming at a reduction of snow load cases.

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1. Introduction

Mountainous regions are preferred locations for solar thermal applications owing to the high irradiation levels, the dry atmosphere and the snow induced high ground reflection in winter times. However, in prolonged periods of bad weather such places may from time to time encounter massive snowfalls leading to very high snow loads on the collectors. From a building insurances point of view, these rare conditions define the minimum requirements given by the building codes [1] for such regions. As an example: The Swiss valley Engadine with the famous city of St. Moritz is located at approximately 1900 m altitude above sea level, the snow loads according to the applicable building codes [2] may easily exceed 10 kN/m^2 on the ground, without considering any safety factors.

For these regions the current standard test procedures for collectors as defined in the standard ISO 9806 are not suitable anymore to rate the resistance to these loads for several reasons:

- The recommended standard test loads are too low and the collector inclination is not considered at all.
- No minimum test duration is defined and mechanical fatigue effects are ignored.
- The interfaces between collectors, mounting systems and the substructures are not thoroughly considered.
- Test rigs for large collectors are not available.

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The effective snow load on a building is calculated in most national building codes on the basis of the snow load on the even ground multiplied by several factors considering wind, geographical location and the roof shape which is described by a form-factor. This form-factor is usually set to zero for inclination angles above 60° (Fig. 1) assuming that under high angles snow will slide down from the roof anyway, hence that snow load is not possible anymore. Experience with damaged collectors installed under almost 70° inclination indicate that this assumption might be wrong for some surface elements such as the well-insulated solar thermal collectors (Fig. 2). Furthermore, snow slides usually have to be prevented for safety reasons, thus further increasing the snow load on the roofs. It is also for safety reasons that in some alpine regions flat roofs are common or even mandatory, so that solar thermal collector systems have to be installed on stands.

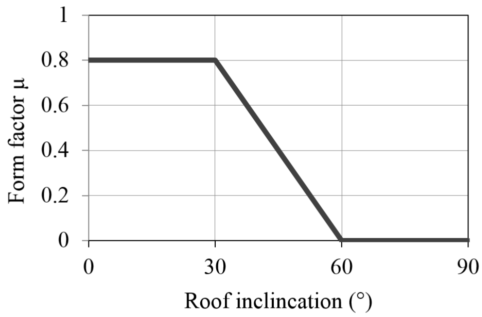

Fig. 1: Form factor for the roof inclination

Fig. 2: Balustrade mounted collectors damaged by snow load

As a result of the inadequate product standards and building codes, manufacturers, installers and building insurances operating in this alpine market notice an increasing number of damage cases over the last years. As there are no tools available to assess, investigate and rate the snow load resistance under controlled extreme conditions, there is currently a distinct risk that building owners, architects and planners refuse installing solar thermal systems in certain regions. To close the gap between product standards, building codes and the reality of alpine regions, a new test rig was developed, addressing the above-listed inadequacy of the current standards for solar devices.

2. Technical setup of the new snow load test rig

Different approaches to simulate snow loads on sloped roofs are known and have been evaluated. The standard test method is based on an extension of the standard test apparatus using pneumatically actuated suction cups. This approach is basically limited by the adherence of the suction cups on the sloped collector surface and is not really applicable for evacuated tube collectors. Furthermore using these suction cups under bigger angles may induce unwanted spots of high forces or tilting forces on the surface. Mainly for this reason, the method was considered as inadequate for our purposes. Other simple methods such as piling up sand bags reach their limits, not only for safety reasons, when testing with snow loads of several hundred kilograms. As a consequence of our review of different test methods and after several unsatisfactory attempts to modify our own standard test facilities a completely new test rig developed.

The core idea of the new system is to divide the required resulting force on a sloped collector into a parallel and a perpendicular component with respect to its surface (Fig. 3). The collector is installed with its mounting kit on a horizontal ground, simulating any roof structure. The forces perpendicular to the surface F_N are applied with a pressure-controlled air cushion, made of a thin polyurethane foil (Fig. 4, right). The flexible material is perfectly suited to provide a homogenous load corresponding to evenly distributed snow, without inducing local peak forces potentially causing early glass breakages. Furthermore the pressure remains homogeneous even if the sample is already being deformed by the load. Although basic physics, it is worth noting that pressurizing a cushion to provide all thinkable real snow loads requires only very low pressures in a range of less than 200 mbar. The whole test rig is enclosed in a very stable and stiff enclosure made of a steel frame with honeycomb sandwich structures to absorb these forces.

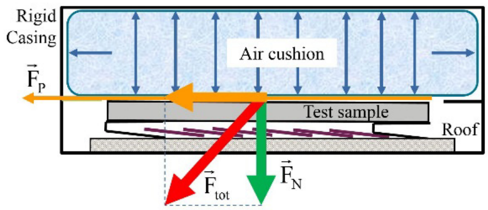

Fig. 3: Schematic setup of the new test rig.
F_{tot} is the resulting snow load on the collector,
F_P and F_N the components parallel and vertical to the surface.

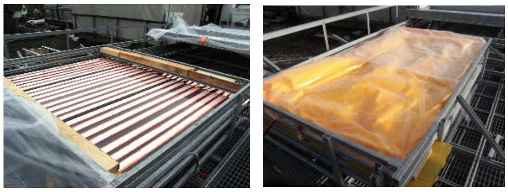

Fig. 4: Photographs of the test rig
(Left) Straps for the application of the parallel forces
(Right) Installation of the air cushion.

The downhill-slope forces F_P parallel to the collector surface are simulated using evenly distributed unidirectional glass-fiber straps, coated with a specially developed sticky silicone layer (Fig. 4, left). It is important not gluing the straps on the glass surface to prevent from a possible structural reinforcement of the cover. With the currently used silicone mixture, the straps can be removed from the collector after testing without leaving any remains, at least for an unbroken glazing. The straps are operated using precisely force controlled electric winches and tackles.

By simultaneously pulling the straps and pressurizing the air cushion the resulting force F_{tot} can be adjusted to simulate almost any snow load on any roof inclination under exactly controlled conditions. This new approach is realized in an up to 15 m^2 test rig that allows the snow load testing of very large size collectors or small fields of collectors at snow loads on ground of up to 20 kN/m^2 under almost any inclination.

Several cameras are installed to visualize all events in real-time and to generate time-lapse videos later on (Fig. 5). These videos have proven to be a very useful tool for locating weak points of a construction as the structural damages and crashes can be followed at any point without any risk for the observer. Several distance sensors are placed all over the test sample to monitor the deformations and to put them in relation to the applied loads. As shown in Fig. 5 all the information about the collector deformation (blue bars, upper right), the applied forces (graph on lower right showing F_P and F_N) is then correlated to the video pictures to get the full information on one screen.

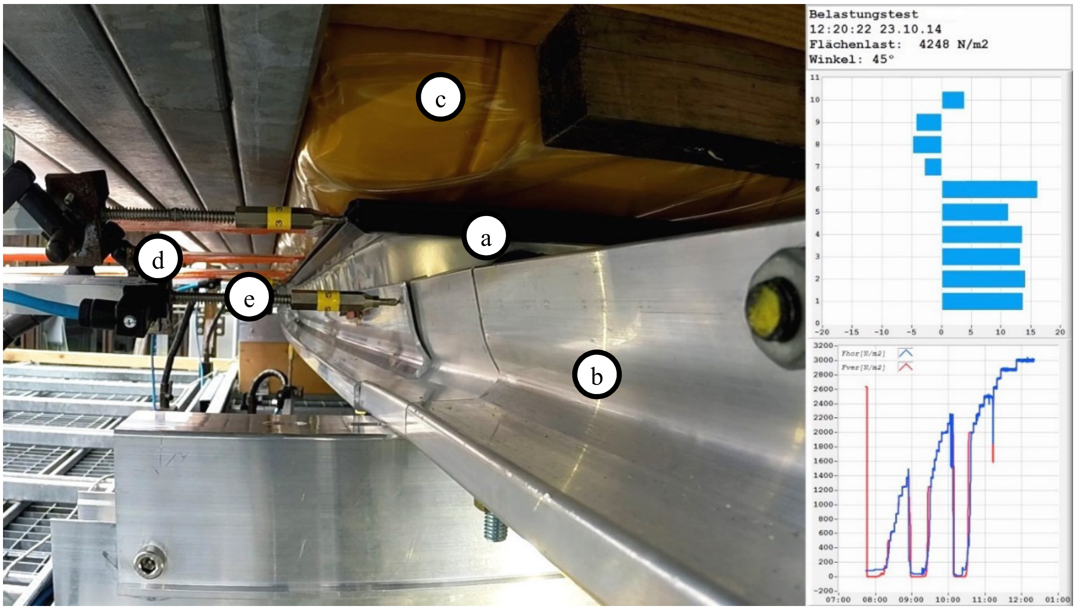

Fig. 5: Example of screen shot of a trough collector (a) with its mounting system (b) under load. On top the air cushion (c) for the vertical load, the straps (d) provide the parallel forces. Up to ten deformation sensors (e) are installed. The blue bars (right side) provide the online information of all deformation sensors. The loads in vertical and horizontal direction as a function of time are displayed on the lower right,

3. Validation of the test method

The test method using the new test rig has been validated thoroughly by reproducing several real snow load cases under laboratory conditions in the test rig. These installations were inspected on-site to capture all damages and if possible, the collectors were taken to the laboratory as reference. In collaboration with the manufacturers, exactly the same collector installation concerning inclination, installation method, roofing and using the same collectors and mounting kits were simulated on the test rig. The maximum snow load having led to the damages on the collector field had to be estimated using photos, reports in newspapers, adjacent official measuring stations, reports from the neighbors and building insurance information. Based on these estimations the collectors were tested up to the maximum load that was assumed for the considered cases.

These validation simulations have shown that the observed damages are in very good agreement with the real cases. Furthermore, it was found that the test loads required to induce the damages are matching the snow loads of the real cases. The precision of such a validation based on real cases is limited, as the damage of a solar device is usually noticed only in spring, hence a long time after the damage had happened. However, for the considered cases the snow loads on the devices were rather well known and the validation is therefore considered successful for flat plate collectors, evacuated tube collectors and also for PV systems.

4. New test procedure

To simulate the snow loads occurring over a lifetime of a solar thermal system, a dedicated test procedure was developed imitating snowfalls and melting phases for average-, hard- and extreme winters during 30 years with increasing snow loads up to 13 kN/m^2. This standard maximum load was selected because of the applicable Swiss building code, but the tests can be extended up to 20 kN/m^2 upon request and to include also safety factors. To obtain a reliable rating, the test samples always include the well-defined mounting system and the tests are made in different slope ranges. A complete test cycle consists of approximately 1800 different load and unload phases where some sequences are prolonged to several hours to consider also creeping effects (Fig. 6). A complete testing cycle therefore usually takes up to three weeks.

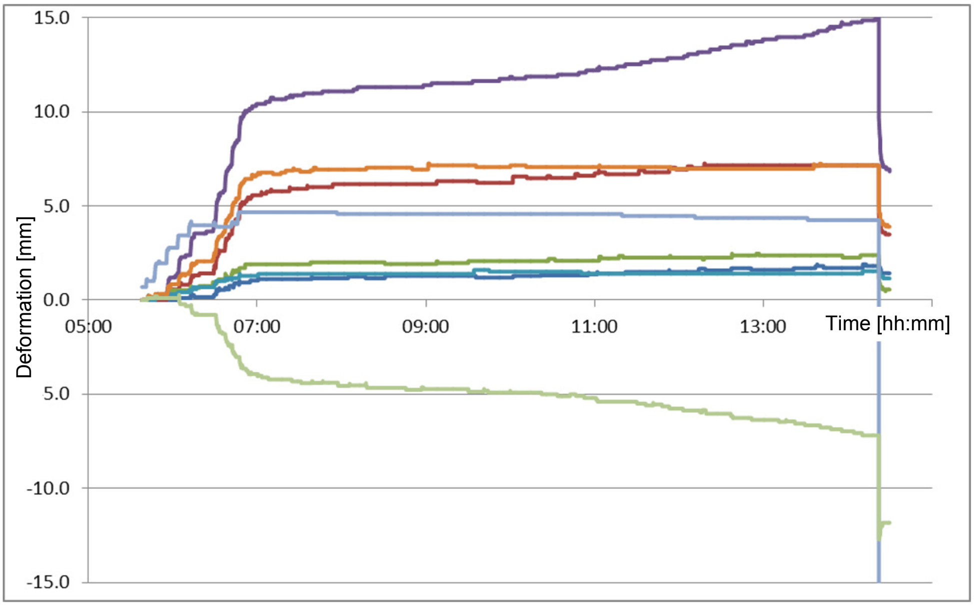

Fig. 6: Deformation of a collector under constant load (load held constant after 07:00) measured at different locations plotted versus time. At some points of the collector, the deformation stops immediately after reaching the maximum load. For some other locations, the deformation seems to cease (e.g. top and bottom curve) but then after several hours starts increasing again until the mechanical breakdown after about 8 hours.

As a result of the successful validation, a dedicated certification procedure for flat plate collectors, evacuated tube collectors and PV-modules based on the developed test procedure was established together with the Swiss Association of Public Insurance Companies for Buildings (APIB), aiming at a considerable reduction of the snow load cases in alpine and sub-alpine regions.

5. Results

Several test with different test samples have been made. One of the main results is that test duration is crucial. In several cases, test collectors have been damaged only after several hours of maintaining stable loads. Fig. 6 shows the continuous deformation of a collector under constant snow load, measured at several positions. After several hours of almost stable deformation, the collector glass crashed suddenly. Under standard testing conditions as given in the ISO 9806 without defined time limit, such a test would have been considered as passed after a few minutes.

Concerning the different collector constructions it was confirmed that the downhill forces often result in rather different deformations of the casing and mounting structures compared to the normal forces testing. High snow-loads always induce a certain deformation of the collector casing. If this deformation is symmetric as it is usually the case in ISO9806 testing, a normal casing can be considered to some extent as a self-stiffening construction. These deformations may not be symmetric anymore under sloped loads, leading to an imbalance of the forces and hence to further deformations and earlier break-down of the construction. The new test rig with the sensors and cameras has proven to be a valuable tool for the verification of corresponding computer simulations made by some of the manufactures. The resulting better understanding of the collector statics is then the key for snow load resistant collector constructions which can be installed also in mountainous regions with at times extreme snow conditions.

Acknowledgements

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